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DETERMINATION OF BOND STRENGTH BETWEEN THE HARD-FACED (HF) LAYER AND THE BASE MATERIAL (BM) OF FORGING DIES

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This paper points out complex working conditions of forging dies, which are the most frequent causes of their damage, and proposes suitable hard-facing repair procedures. The shear strength between the hard-faced layer and base metal has been measured using specially developed tool, and correlation between output results and the applied hard-facing technology is established.

Key words: forging dies, alloy steel, hard-facing, hardness, microstructure

INTRODUCTION

Improved performance and prolonged lifetime of industrial components and machineries, often require different kinds of repairment, particularly for large and heavy installations, [1-15]. The weld deposition of hard-facing alloys is commonly employed in industry, to increase the lifetime of components subjected to different kinds of wear [6,7]. The lifetime of dies, used for production of forged parts, is variable and determined by wear rate, plastic deformation, and thermal and mechanical fatigue. Those tools are subjected to extreme temperature at high unit pressures, for short durations, and must withstand multiple cycles while maintaining dimensional stability. Occurrence of damage on a pair of hot-forging dies has been analyzed in [14]. Three mechanisms of wear were detected on dies surfaces, which are thermal fatigue, mechanical fatigue and abrasion. A couple of important issues in engineering failure analysis of hot forging die failures, for automotive components, are summarized in [14], mainly from authors own experimental results. In this paper, the optimal technology of hard-facing repair of forging dies has been assessed, based on the shear strength. Since some parts of the forging dies are extremely exposed to shear during hot forging, it is vital to establish a relation between the shear strength of base material (BM) and hard-faced layer, hard-facing technology and heat treatment. Toward this aim, a special tool was constructed and mounted on a universal testing machine to enable estimates of absolute and relative bearing capacities of the characteristic cross-sections. This paper also deals with the most frequent causes of damage, types of steel used for forging dies, choice of hard-facing technology and filler metals. All the tests were performed on the same material as the forging dies, enabling output results to be correlated to the chosen procedure and hard-facing technology.

FORGING TOOL MATERIALS AND THEIR PROPERTIES

Hot work steel tools must have good mechanical properties, such as strength and toughness, not only at room temperature, but also at high temperatures. They also must have high resistance to wear, sufficient hardenability, good thermal conductivity, stability during processes of oxidation and decarburization, low coefficient of linear expansion and high resistance to surface cracking at repeated heating and cooling [6,7]. If temper embrittlement appears, it can sometimes be eliminated by technological measures that involve rapid cooling in the temperature range of 500 - 550 ºC. Forging dies and press tools operate at elevated temperatures, up to 600 ºC, and they are subject to static loading and impact. Steel alloys with Cr, V, Mo, and 0,3 - 0,6 % C have good hardenability at elevated temperatures. Hard-facings (HF) of two typical steels used for forging dies were studied: 55CrMo 8 (EN), used for all kinds of forging tools, and X27CrMoV 51 (EN), used primarily for casting dies of nonferrous metals, particularly aluminum alloys and brass. Their chemical composition is given in Table 1, and mechanical properties and microstructure in Table 2.

Since forging dies used in blacksmithing are in quenched and highly tempered condition, all the samples, here used, were also quenched and tempered in order to simulate the real operating conditions. After the

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heat treatment, hardness was measured, varying from 40 - 42 HRC for the steel 55CrMo 8, and from 41 - 49 HRC for the steel X27CrMoV 51. Because of the carbon content (C > 0,35%) and the thickness of the hard-faced layers, preheating up to the temperature of about 300 °C was necessary.

THE HARD-FACING TECHNOLOGY AND FILLER METALS

In order to select the most suitable hard-facing technology numerous tests were performed on samples, whose dimensions were determined based on the similarity theory, i.e. based on non-dimensional analysis. Criteria of hard-facing quality were the hardness and structure changes in the hard-faced layer zones and, in the heat affected zone, beneath the hard-faced layer. Hard-facing was performed using manual metal arc (MMA) process with coated electrodes with commercial names UTOP 38 and UTOP 55. Prior to their usage, the electrodes were dried applying following procedure: heating up to 350 - 400 °C, keeping at the drying temperature for 2 hours and then cooling in the furnace for 1 hour at the temperature not lower than 150 °C. Such heated electrodes were used for hard-facing of preheated samples in order to reduce the level of diffusive hydrogen and appearance of hydrogen induced cracks. The hard-facing rate was prescribed in each pass, and prior to each pass the preheating temperature, i.e. the inter-pass temperatures, were checked. The digital measuring device Tastotherm D 1 200 with the thermocouple NiCr-NiAl and the measuring range from -50 to 1 200 °C has been employed. Layers hard-faced with these electrodes are tough, resistant to wear and impact, with constant hardness up to the temperature of 600 °C, as claimed by the manufacturer, or up to 570 °C as established in our tests [14]. In Tables 3 and 4 hard-facing parameters and filler metal (FM) properties are shown.

The sequence of hard-faced (HF) layers deposition is given in Figure 1a. Prior to each pass the layer of slag was removed with a steel brush. All other layers were deposited using this pattern, as is shown in Figure 1b for second, and in Figure 1c, for third pass. The width of the hard-faced pass, with the electrode ∅ 3,25 mm, was $b \approx$ 10 - 12 mm and its height was $h \approx$ 1,5 mm. When the electrode ∅ 5,0 mm was used, the width of the pass was $b \approx$ 16 - 18 mm, and the height was $h \approx$ 2,1 mm. Hard-faced samples were tempered at the temperature T_{tem}= 340 ºC (2 h), [14].

Table 1 **Chemical composition and labełling for 55CrMo 8 and X27CrMoV 51**

EN	Chemical composition / %									Relation to other standards	
	C	Si	Mn	P	S	Cr	Ni	Mo	V	DIN	UNI
55CrMo 8	0,55	0,3	0,7	0,035	0,035	1,1	1,7	0,5	0,12	56NiCrMoV7	U52NiCrMo6KU
X27CrMoV 51	0,40	1,0	0,4	0,025	0,025	5,0	-	1,3	0,4	X38CrMoV5	UX35CrMo05KU

Table 2 **Mechanical properties and microstructure of 55CrMo 8 and X27CrMoV 51**

EN	Soft annealing			Tempering			Preheating temperature T / °C	Microstructure, of base material (BM)
	T / °C	HV_{max}	R_m / MPa	T / °C	HRC	R_m / MPa		
55CrMo 8	670 - 700	250	850	400 - 700	50 - 30	1 700 - 1 100	≈ 300	martensite (M) + bainite (B)
X27CrMoV 51	800 - 830	250	850	550 - 700	50 - 30	1 700 - 1 100	≈ 300	martensite (M) + bainite (B)

Table 3 **Hard-facing parameters for MMA method**

BM	Electrode labełling		Electrode Diameter / mm	Hard-facing current / A	Voltage / V	Hard-facing velocity / cm/s	Heat input energy / J/cm
	Jesenice	DIN 8555					
55CrMo 8	UTOP 38	E3-UM-40T	3,25	115	26	≈ 0,28	8 543
X27CrMoV 51	UTOP 55	E6-UM-60T	5,0	190	29	≈ 0,25	17 632

Table 4 **Filler material properties [7]**

BM	Electrode labelling		Chemical composition / %						Application
	Jesenice	DIN 8555	C	Cr	Mo	V	Current type	Hardness / HRC	
55CrMo 8	UTOP 38	E3-UM-40T	0,13	5,0	4,0	0,2	= (+)	36 - 42	Hard-facing of hot and cold work tools
X27CrMoV 51	UTOP 55	E6-UM-60T	0,5	5,0	5,0	0,6	= (+)	55 - 60	Hard-facing of hot and cold work tools

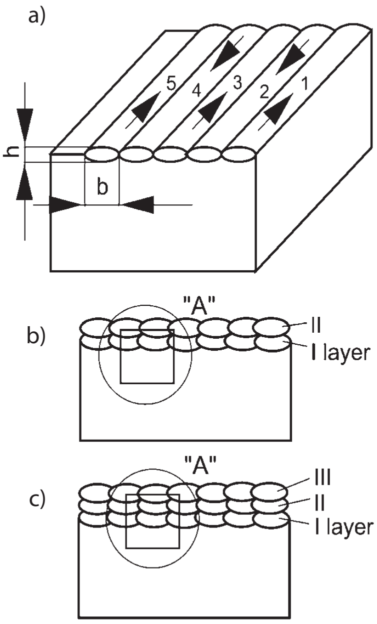

Figure 1 The sequence of the hard-faced layers deposition: a) I layer, b) II layers, c) III layers

PREPARATION OF SPECIMENS

The plates with two or three hard-faced layers were used to prepare specimen, corresponding to the area “A” in Figure 1, and shown in Figure 2. The area for the hardness measurements and metallographic tests was polished and etched with nital solution. When the hard-faced layer structure was determined, it was etched with aqua regia (20 - 30 ml HCl + 10 ml HNO_3 + 20 - 30 ml glycerine), revealing base material (BM), Heat-affected-zone (HAZ) and hard-faced (HF) layer, Figures 2b and c. Shear strength of the cross section of the specimen was then determined.

Having in mind different capacities of testing machines (10 kN for the mechanic and 40 kN the hydraulic one), the cross section of the specimen for shear testing has been taken as 15 × 7 × L_o for the mechanic testing machine, and as 30 × 10 × L_o for the hydraulic testing machine, were L_o, mm, is the specimen length. Using the base metal hardness, measured on hard-faced plates, the tensile strength can be estimated.

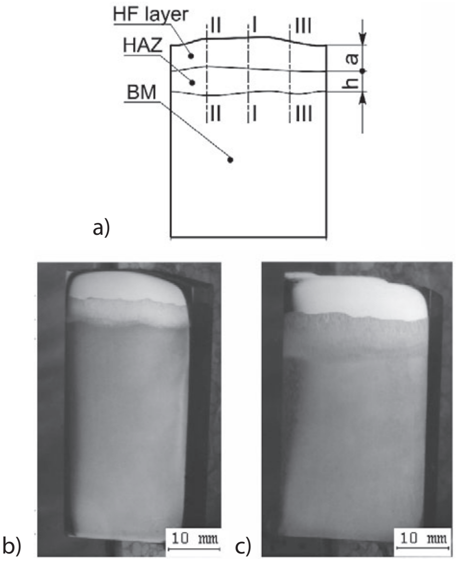

Figure 2 Hard-faced specimens: a) measurement directions, b) two layers, c) three layers

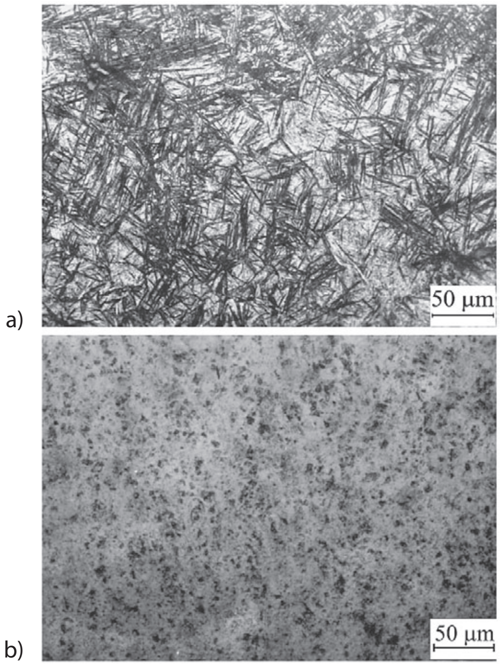

Figure 3 Microstructure in HAZ: a) 55CrMo8 with UTOP 38 – Ø 3,25 mm, b) X27CrMoV 51 with UTOP 55 – Ø 5,0 mm, magnification 200 x

As seen in Table 5, when hard-facing is performed with the electrode UTOP 38 – Ø 3,25 mm, needle-like martensitic structure is formed in the HAZ, Figure 3a, due to lower heat input energy - q_l, higher cooling rate - v_h, i.e. shorter cooling time - $t_{8/5}$. When the electrode UTOP 55 – Ø 5,0 mm was used, a much more favorable interphase structure, with very small finely dispersed carbide inclusions, Figure 3b, has been obtained.

SHEAR TEST RESULTS

After the specimens have been prepared, experiments were carried out with the aim to determine the shear strength between the hard-faced layer and the BM, as well as the shear strength of the BM itself. Special tool was designed and used on a universal testing machine. Specimens marked as 9, 11, 13 and 15 represent the steel 55CrMo8, whereas marks 10, 12, 14 and 16 represent the steel X27CrMoV 51, as given in Table 6a and 6b. Table 6a indicates shear strength values between 766 and 1 521 MPa for the bond between hard-face layer and the BM 55CrMo 8, and between 886 – 1 161 MPa for the bond between hard-face layer and the BM X27CrMoV 51. Table 6b indicates shear strength for the BM 55CrMo8 between 886 and 1 070 MPa, and for the BM X27CrMoV 51 between 830 and 1 112 MPa.

Comparing these results, it is obvious that the shear strength between the hard-faced layer and the BM has reached satisfactory level for both BMs, since the range of its values corresponds well with the range of values for shear strength of the BM.

Table 5 **Basic data for the specimens**

Substrate material	Hard-faced layer material	Number of layers	Hard-faced layer thickness / mm	HAZ width h / mm	Microstructure hard-faced layer / HAZ
55CrMo8	UTOP 38 Ø 3,25 mm	2	3,0 - 4,5	3,5 - 4,5	Needle-like martensite (M) with traces of residual austenite
X27CrMoV 51	UTOP 38 Ø 3,25 mm	2	3,5 - 4,5	3,0 - 4,0	Interphase structure with very small carbide grains + M
X27CrMoV 51	UTOP 55 Ø 5,0 mm	2	5,0 - 7,0	3,0 - 4,0	Interphase structure with very small carbide grains + M
55CrMo8	UTOP 55 Ø 5,0 mm	2	5,5 - 7,0	7,5 - 9,0	Mixed-interphase martensitic and bainitic structure (M+B)
X27CrMoV 51	UTOP 55 Ø 5,0	3	6,0 - 8,0	4,0 - 5,0	Interphase structure with very small carbide grains + M
55CrMo8	UTOP 55 Ø 5,0 mm	3	6,0 - 7,0	5,0 - 6,0	Mixed-interphase martensitic and bainitic (B) structure (M+B)
55CrMo8	UTOP 38 Ø 3,25 mm	3	5,0 - 6,0	4,0 - 5,0	Needle-like martensite with traces of residual austenite
X27CrMoV 51	UTOP 38 Ø 3,25 mm	3	6,0 - 7,0	3,3 - 4,0	Interphase structure with very small carbide grains + M

Table 6a **Shear strength for the bond between FM and BM**

Specimen mark – BM - FM	Shear strength / MPa
9 - 55CrMo8 - UTOP 38-2	766
11 - 55CrMo8 - UTOP 55-3	1 107
13 - 55CrMo8 - UTOP 38-3	1 521
15 - 55CrMo8 - UTOP 55-2	1 277
10 - X27CrMoV 51 - UTOP 55-3	1 041
12 - X27CrMoV 51 - UTOP 38-2	1 161
14 - X27CrMoV 51 - UTOP 55- 2	873
16 - X27CrMoV 51 - UTOP 38-3	869

Table 6b **Shear strength for the BM**

Specimen mark	BM	Shear strength / MPa
9	55CrMo8	886
11	55CrMo8	900
13	55CrMo8	1 070
15	55CrMo8	942
10	X27CrMoV 51	1 022
12	X27CrMoV 51	1 112
14	X27CrMoV 51	830
16	X27CrMoV 51	1 046

CONCLUSION

Based on the results presented here, in can be concluded that the applied hard-facing repair technology with preheating and post-weld heat treatment, provides optimal results in rebuilding of damage hot work steels surfaces.

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